National Aeronautics and Space Administration

NASA’s Current Plans for ERA Airframe Technology

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Airframe Technology Focus Areas

Airframe system is 1st order effect

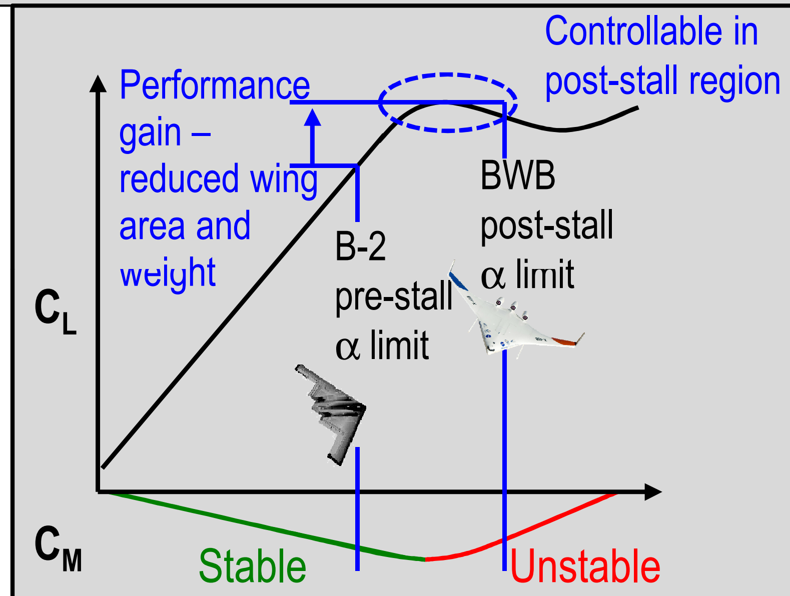
$$\text{Aircraft Range} = \frac{\text{Velocity}}{\text{TSFC}} \underbrace{\left(\frac{\text{Lift}}{\text{Drag}}\right)}_{\text{Aerodynamics}} \ln\left(1 + \frac{W_{fuel}}{W_{PL} + \underbrace{W_{O}}_{\text{Empty Weight}}}\right)$$

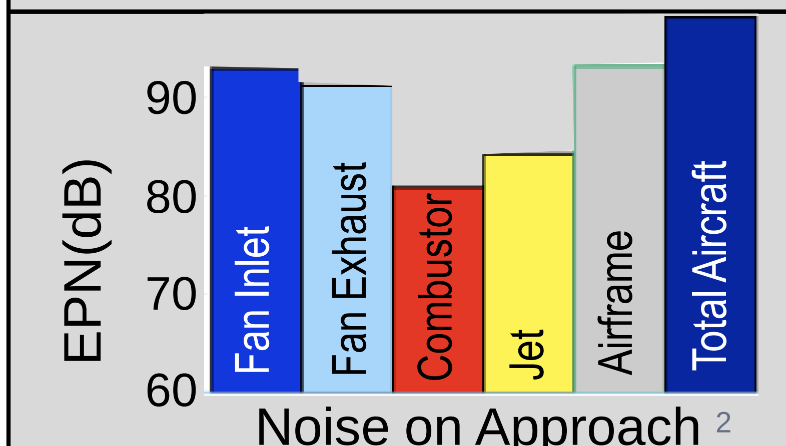
Targets:

- ML/D
- Empty Weight
- Airframe Noise

General Technology Topics:

- Lightweight Structures
- Drag Reduction Technologies
- Flight Dynamics and Control
- Airframe Noise Reduction Technologies





ERA Project

Goals and Metrics and System Studies

CORNERS OF THE TRADE SPACE	N+1 = 2015*** Technology Benefits Relative To a Single Aisle Reference Configuration	N+2 = 2020*** Technology Benefits Relative To a Large Twin Aisle Reference Configuration	N+3 = 2025*** Technology Benefits
Noise (cum below Stage 4)	-32 dB	-42 dB	-71 dB
LTO NO_x Emissions (below CAEP 6)	-60%	-75%	better than -75%
Performance: Aircraft Fuel Burn	-33%**	-40%**	better than -70%
Performance: Field Length	-33%	-50%	exploit metro-plex* concepts

***Technology Readiness Level for key technologies = 4-6

** Additional gains may be possible through operational improvements

* Concepts that enable optimal use of runways at multiple airports within the metropolitan area

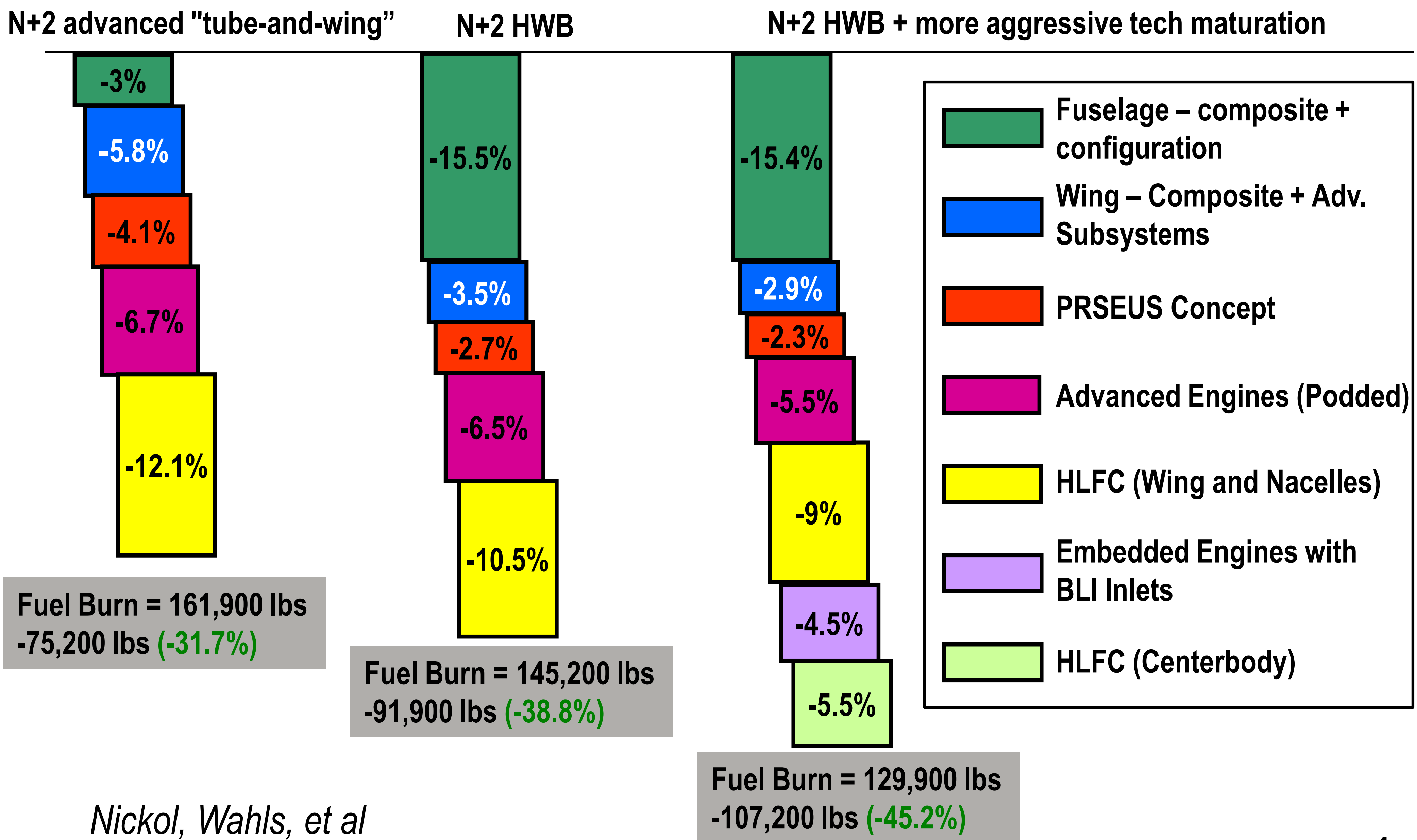
ERA Approach

- *Focused on N+2 Timeframe – Fuel Burn, Noise, and NO_x System-level Metrics*
- *Focused on Advanced Multi-Discipline Based Concepts and Technologies*
- *Focused on Highly Integrated Engine/Airframe Configurations for Dramatic Improvements*

ERA Project

Fuel Burn (and CO_2) Reduction Goal

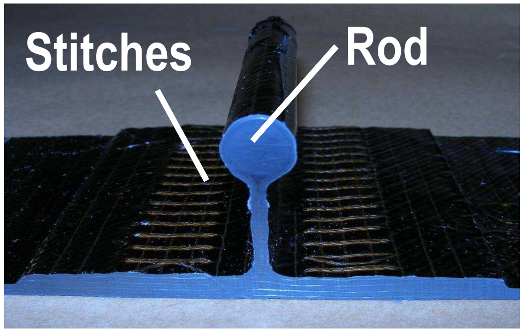
Technology Benefits Relative to Large Twin Aisle (Modeling based upon B777-200 ER/GE90)



Nickol, Wahls, et al

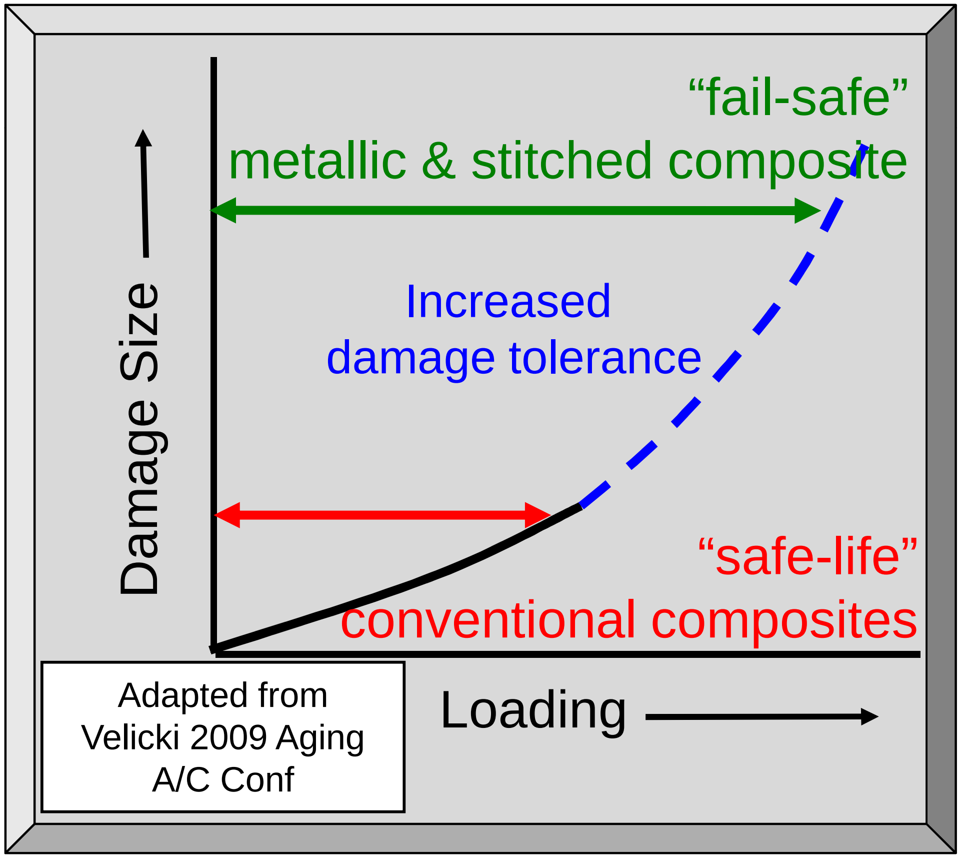
Lightweight Structures
Technical Challenge

- Overcome limitations of primary composite structure designed like “black aluminum”
  - Tailored load path design – reduced weight
  - Design for “fail-safe” instead of “safe-life”
  - Eliminate fastener stress concentrations
  - *Stitched composites - enabling weight reduction with load limit of metal*



Stitched Composite Concept

- Certification and safety requirements
  - **Damage tolerance, durability, flexibility of stitched composites**
  - **Suppress interlaminar failures, arrest damage, control damage propagation**
- Capability for non-circular pressure vessels
  - **Reduce wetted area, enable N+2 vehicle concepts**
- Cabin noise propagation
  - **Lightweight structure**
  - **Propulsion noise shielding**

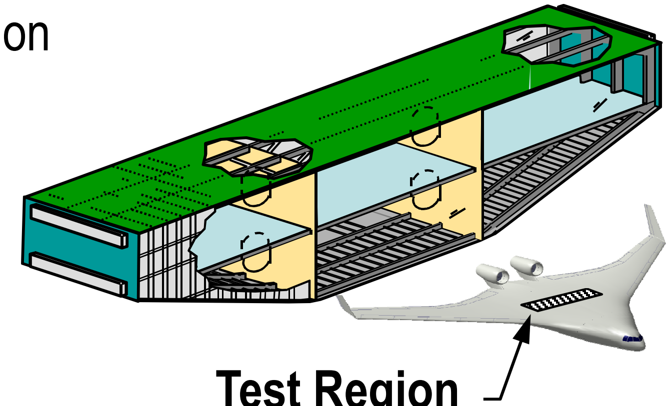


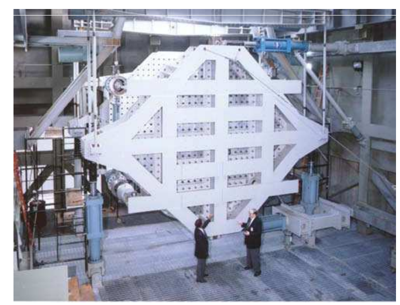
Lightweight Structures

Technical Overview

- **Objective**
  - Explore/validate/characterize new stitched composite structural concept under realistic loads to achieve additional weight reduction
- **Approach**
  - Building block experiments on sub components, joints, cutouts
  - Explore repair/maintenance, NDE methods
  - Large scale pressurized multi-bay fuselage section under combined load
  - Assess noise transmission properties and develop structural design criteria for cabin noise
- **Benefit**
  - Validate damage-arresting characteristics under realistic loads. Expected 10% reduction in weight compared to conventional *composite* structural concepts. Extensible to wings, etc.

Pultruded Rod Stitched Efficient Unitized Structure - PRSEUS





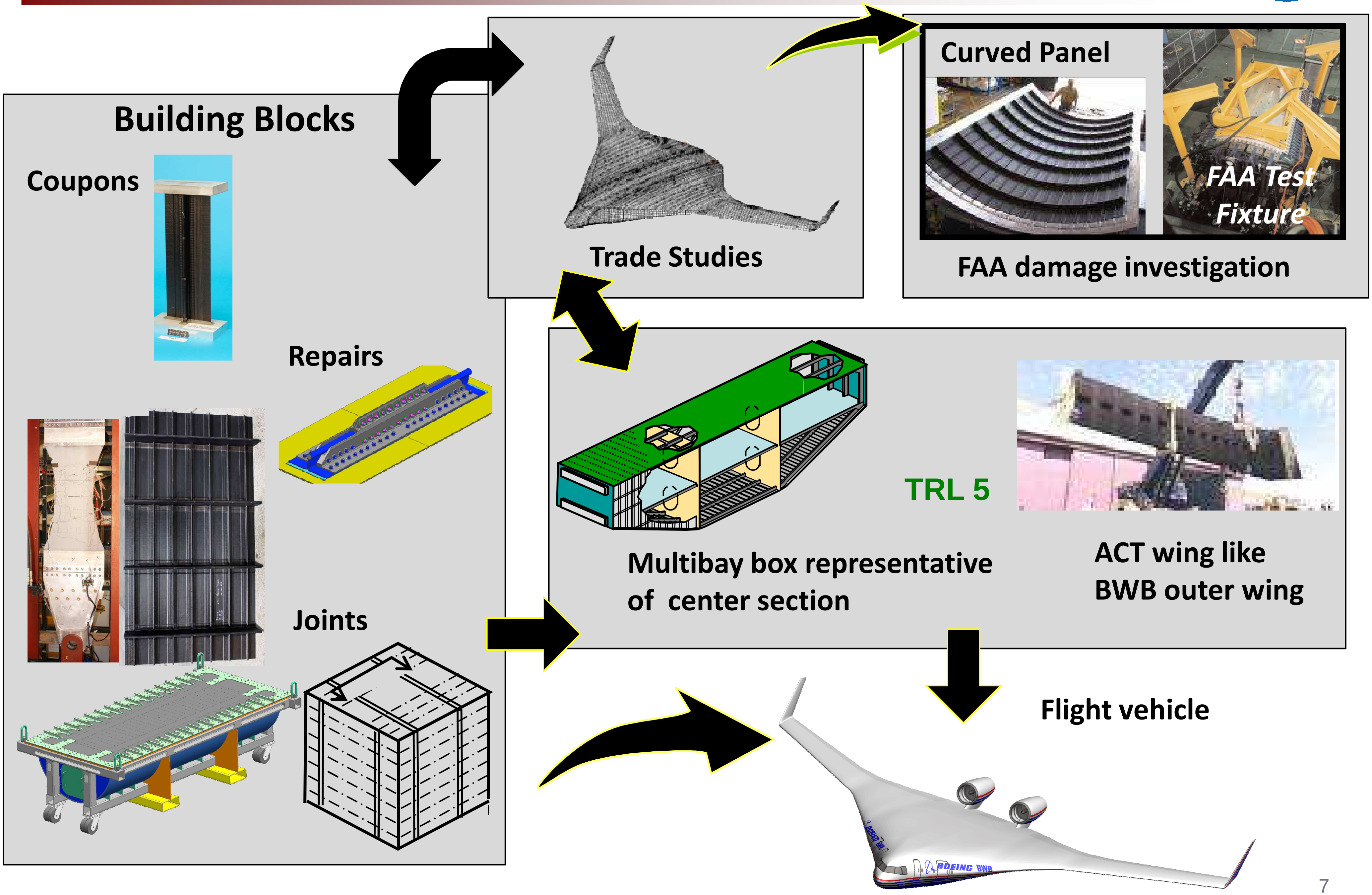
Combined Loads Test Facility (COLTS)

FY10	FY11	FY12	FY13	FY14	FY15

- Complete PRSEUS Pressure and Curved Panel Tests
- Noise Transmission Assessment
- Complete Multibay PRSEUS Tests
- Design Criteria for Low Noise Lt Wt Structure

possibilities
- stitched composite wing
- technology integration (laminar flow, acoustic liners, etc)
- enable unique flight vehicle testbed

PRSEUS Development Roadmap



Flight Dynamics & Control
Technical Challenge

- Even conventional tube and wing aircraft flight control requires extensive wind tunnel testing
  - Half of cost associated with new aircraft development is in control system and integration
  - Most of control design done through empirical database developed over decades of incremental change
    - HWB is at embryonic stage
- Complex validation and verification to develop tools for design and pre-build control system necessary
- Determine stability and control characteristics of commercial HWB class vehicles
  - Meet airworthiness requirements with performance/acoustic benefits?
  - Meet ride quality expectations with performance/acoustic benefits?
- Adaptive controls for performance validated in flight

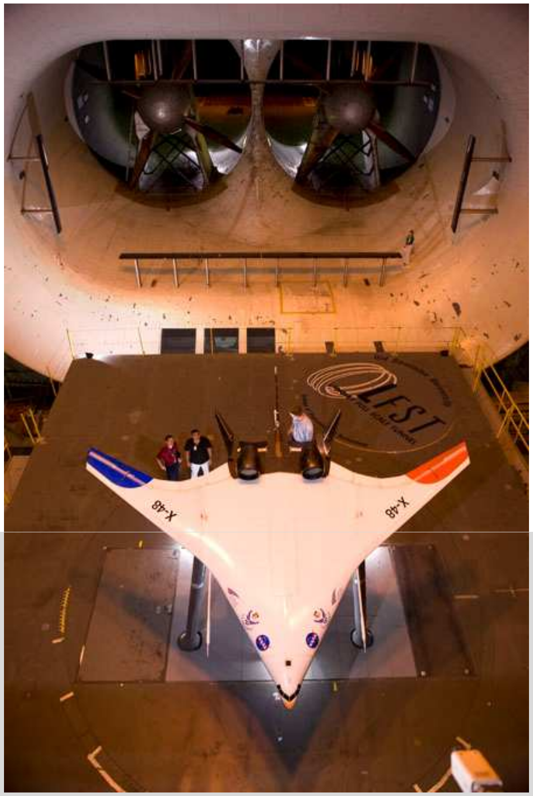
unconventional vehicles provide unique challenges

X-48B

Propulsion for X-48B and X-48C

Flight Dynamics & Control
Technical Overview

- **Objective**
  – Explore/assess flight dynamics and control design space for HWB and derivatives with unique control effector and propulsion combinations
- **Approach**
  – Complete X48B baseline flight tests and demonstrate single surface PID
  – Conduct wind tunnel and flight experiments with advanced propulsion approaches (X-48C, open rotor?)
  – Develop adaptive control approaches to overcome unique HWB flying qualities challenges (ride quality, gust load alleviation, etc.)
- **Benefit**
  – Confidence to proceed to larger scale advanced vehicle concepts with light wing loading



X-48C Full-Scale S&C Test

FY10	FY11	FY12	FY13	FY14	FY15

- Complete X-48C 30’ x 60’ Data Analysis
- Complete X-48B Phase 1 Flight Test
- Begin X-48C Flight Validation
- Complete Intelligent and Constrained Adaptive Control Demo on X-48

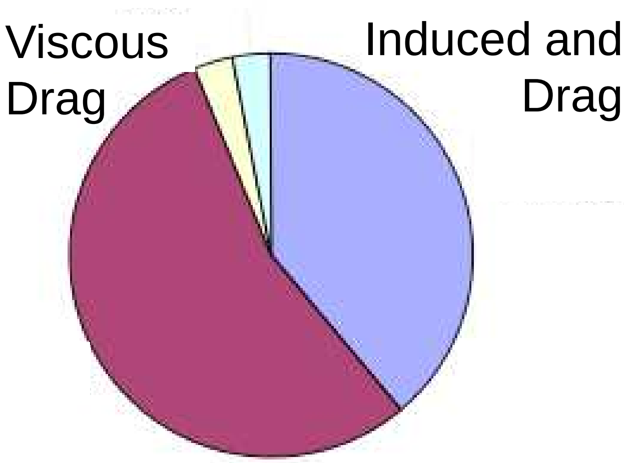
possibilities
- flight experiments with adaptive controls
- other control concepts in piloted simulation
- investigation of lightweight structures
- additional unconventional flight test vehicle

Drag Reduction

Technical Challenge

- ERA N+2 goal of - 40% fuel burn = less cruise drag
  - Laminar Flow (LF) Technologies, wetted area reduction with active flow control (AFC), turbulent drag reduction
- LF Technology aerodynamic benefits are known, ERA break down practical barriers
  - Yet to be exploited on transonic transport aircraft
  - System integration trades – high-lift performance, flight weight suction systems, structural stiffness
  - Robustness – contamination, surface imperfection
  - Pre-flight assessment – ability to ground test/assess across full-flight envelop at relevant conditions prior to flight
- AFC to improved control surface effectiveness
  - System integration trades – pneumatic vs. electric actuation, actuation location, available authority
  - Flight weight actuation, fail-safe control

Active and Passive Concepts

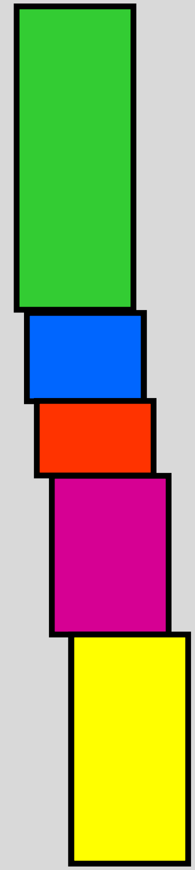


Drag Breakdown (Typical)

Drag Reduction

Technical Overview

- **Objective**
  - Enable practical laminar flow application for transport aircraft
- **Approach**
  - Mature multiple approaches to laminar flow to enlarge trade space
  - Address critical barriers to practical laminar flow application – surface roughness, manufacturing, contamination, energy balance
  - Explore synergy with other advanced technologies (e.g. composite structure, cruise slots, novel high lift systems, intelligent controls, etc.)
- **Benefit**
  - Validated passive and active drag control technologies capable of enabling up to 15 % reductions in fuel burn.
  - Expanded database and design trade space with higher fidelity trade information for transition prediction, manufacturing.
  - Confidence to proceed to highly integrated flight test experiments



N+2 HWB Technology Benefits

High Rn HLFC
- Outboard wing
- Nacelles
- Δ Fuel Burn = -10.5%

FY10	FY11	FY12	FY13	FY14	FY15

▲ Evaluate Ground Test Capability For NLF

▲ Complete 20% Scale Test of AFC Rudder

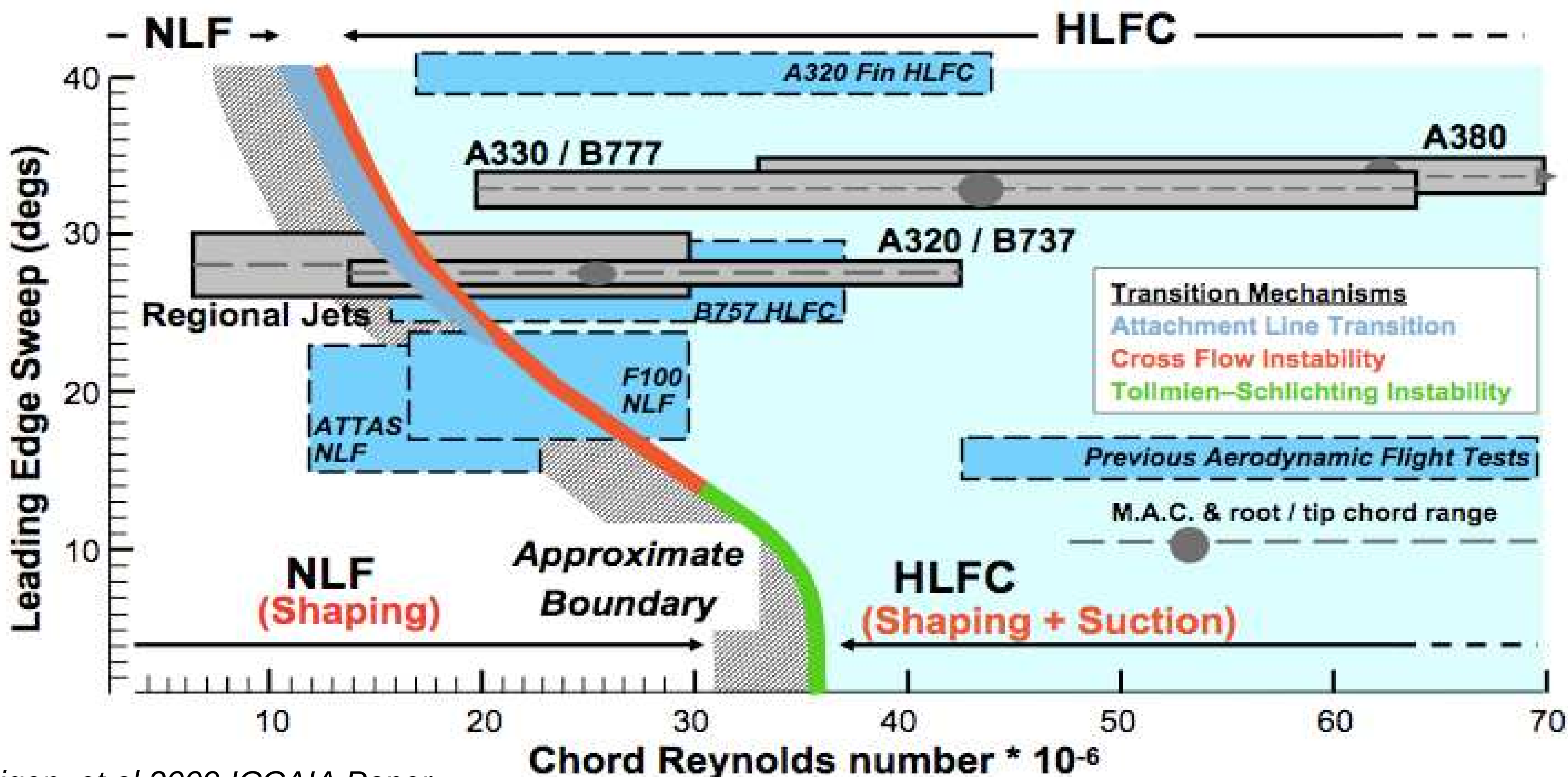
▲ Complete DRE Glove Flight Test

▲ Complete Flight Weight HLFC System

possibilities
- “in-service” flight tests of selected concept(s)
- integrate with other techs (composites, cruise slot)
- re-wing research aircraft
- incorporate in design of flight vehicle testbed
- other drag reduction concepts beyond laminar

Multiple Approaches to Laminar Flow
Phase 1

- Approach dependent on system requirements and trades
- System design decisions/trades
  - Mach/Sweep, Rn, Cp distribution, high-lift system
  - Aircraft components, and laminar extent of each



Vijgen, et al 2009 ICCAIA Paper

ERA Drag Reduction Technologies

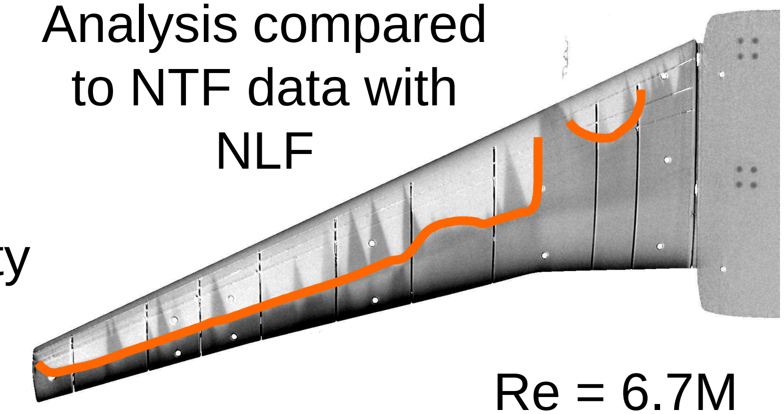
ERA Phase 1

Laminar Flow Technology Maturation

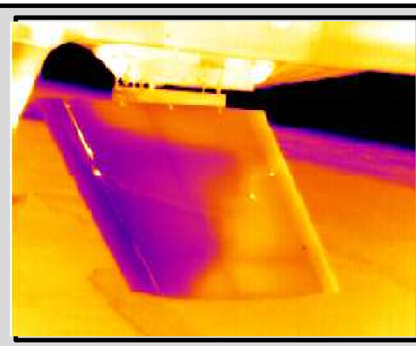
– **Natural Laminar Flow**
  - Link transition prediction to aero design tools
  - Assess and develop high Rn ground test capability

– **Hybrid Laminar Flow Control**
  - Flight weight passive suction system
  - Design, build, fly to show viable operational capability – understand system trades, validate tools

– **Distributed Roughness Elements**
  - Fly wing glove with periodic DRE to Rn = 15M, M = 0.8
  - Passive control to relax surface quality requirements



Re = 6.7M



DRE effect, low M, low Rn

DRE Tech Demo Concept

ERA Drag Reduction Technologies

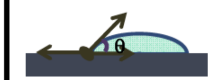
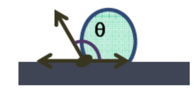
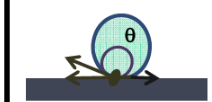
ERA Phase 1

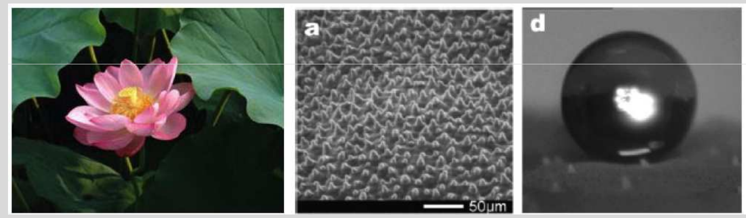
Laminar Flow Technology Maturation

– **Low-Surface Energy Coating**
  - Demonstrate coatings for insect impact protection on NASA G-III
  - Develop abhesives with very low surface energy
  - Use surface engineering for controlled roughness to enhance hydrophobicity

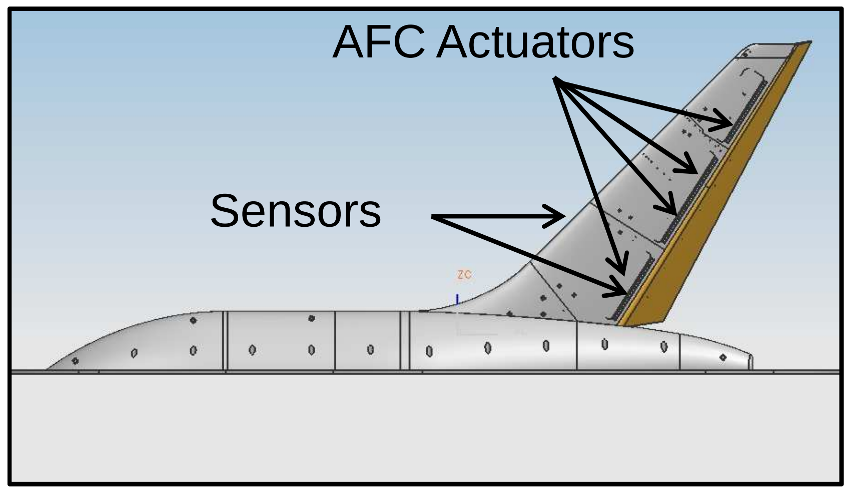
Active Flow Control Maturation

– **Increased On-Demand Rudder Effectiveness with AFC**
  - Apply fluidic oscillating jets and/or synthetic jets near the rudder hinge line
  - Benefit is smaller vertical tail
    - Less weight and wetted area in cruise
    - AFC only needed for engine out
  - Experience gained for AFC certification in other applications

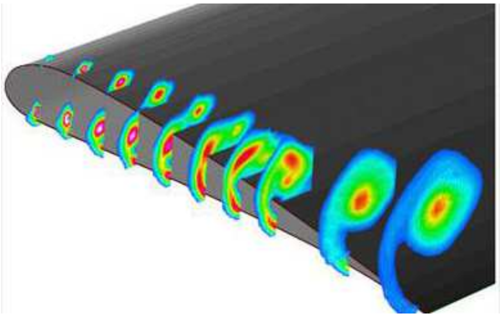
Classification	Contact Angle	Example
Hydrophilic	θ< 90	
Hydrophobic	150>θ> 90	
Super-Hydrophobic	θ> 150	

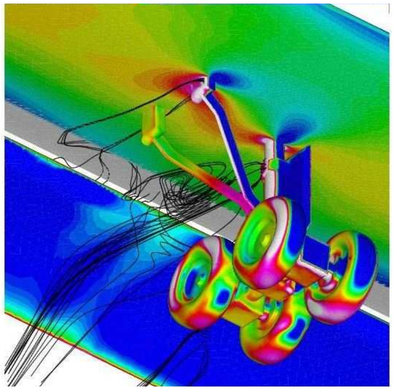


Controlled roughness example

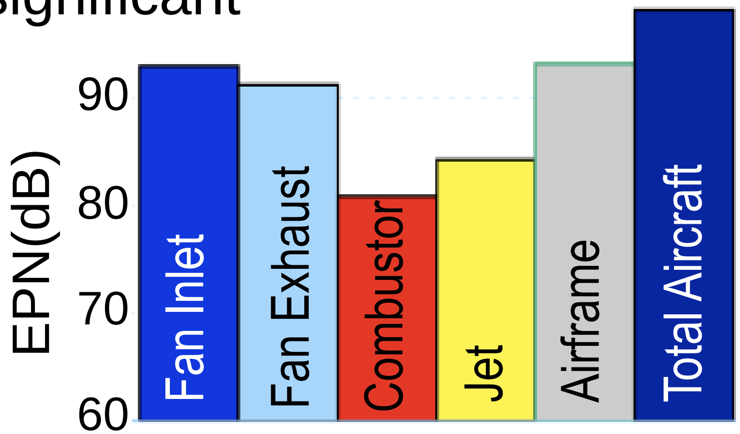


Airframe Noise Reduction
Technical Challenge





- Airframe noise not well understood or modeled
- Airframe noise reduction technology often conflicts with other requirements
  - **Landing gear designed for performance/weight but generate much more noise**
  - **High lift slats/flaps generate noise**
- Currently cannot accurately account for aircraft noise sources, interactions, installation effects
- Cannot meet N+2 goals with current technology
- Must reduce all three components to achieve significant reductions
  - **Continuous mold line technology**
  - **Reasonable landing gear fairings**

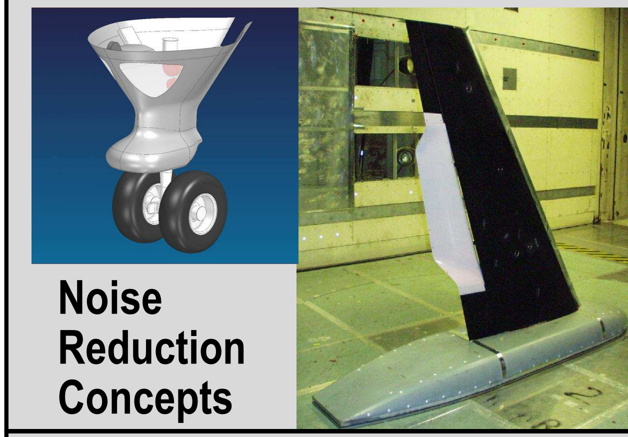


Noise on Approach

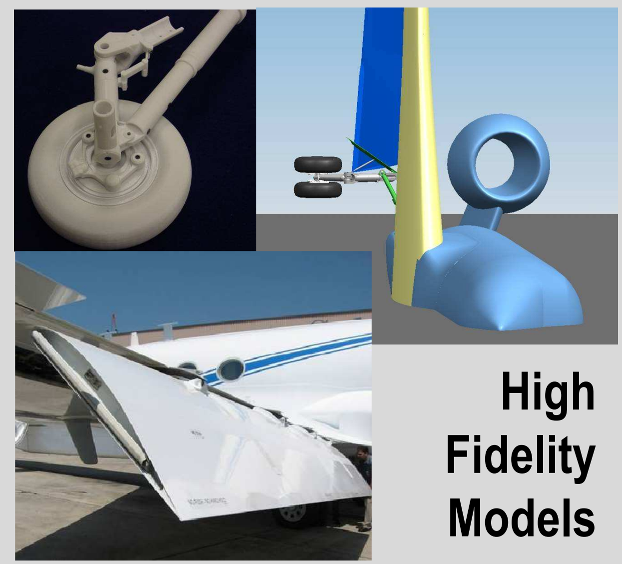
Airframe Noise Reduction

Technical Overview

- **Objective**
  - High fidelity measurements/modeling of structural, fluidic, and acoustic interactions for flap side edge, landing gear
  - Develop quiet flaps and landing gear <u>without</u> performance penalties
- **Approach**
  - Flight test of CML flap on NASA G-III aircraft
  - Wind tunnel campaign targeting landing gear and flap edge noise as well as gear/flap interactions.
  - Flight test of flap edge concepts on Gulfstream G550
    - Improved microphone array technology used on flight test
- **Benefit**
  - Quantified technologies for airframe noise reduction on the order of 5-10 dB cum; enlarged design trade space for adv. low noise configurations



Noise Reduction Concepts



High Fidelity Models

FY10	FY11	FY12	FY13	FY14	FY15

▲ Low Noise Concepts Tested in 14x22

▲ Validate Low Noise Flap Edge and/or Gear Noise Concepts in Flight

<u>possibilities</u>
- large-scale or flight experiments on low noise vehicle with adv. airframe NR technologies

Concluding Remarks

- System Studies identify fuel burn improvements to meet ERA goals through
  - Weight reducing stitched composites structures
  - Practical application of laminar flow technologies
  - System-Level Approach
- Key Airframe System Technology Demonstrations
  - Multi-bay PRSEUS pressure/combined load test
  - High Reynolds number demonstrations of NLF, DRE, and HLFC laminar flow techniques to overcome practical barriers
  - Low-speed full envelop demonstrations of HWB concepts for robust flight control
  - Full-scale flight demonstrations of airframe noise reducing technologies for high-lift and landing gear
- Partnerships with industry are integral key to achieve ERA goals

NASA